

Field incidence of mycotoxins in commercial popcorn and potential environmental influences

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Received: 6 September 2009 / Revised: 20 October 2009 / Accepted: 22 October 2009 / Published online: 20 November 2009
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Abstract Popcorn ear damage by insects and mycotoxin levels in kernels were monitored in several commercial popcorn fields in central Illinois over a 4-year period. Aflatoxin was rare, but fumonisin and deoxynivalenol (DON) were commonly encountered each year, and occurred at mean levels in fields up to 1.7 mg/kg (sample max. 2.77 mg/kg) and 1.9 mg/kg (sample max. 2.66 mg/kg), respectively. Neither fumonisin nor DON levels were significantly correlated with the percent of ears with visibly moldy insect-damaged kernels. Significant correlations were noted for the percent of ears with early caterpillar damage and both fumonisin and DON levels overall for some years and at specific sites in other years. Fumonisin levels were generally more highly correlated with insect damage than DON levels. Insect damaged kernels had 100- to 500-fold or greater levels of fumonisin compared to noninsect-damaged kernels, while DON levels were closer to 10- to 30-fold higher in insect damaged versus non-damaged kernels. A high percentage of DON-contaminated kernels were not insect damaged in 2007 and 2008. In some cases, differing mycotoxin levels for the same hybrid and same year planted at different locations appeared to be due to the prior crop. Higher DON levels in 2008 than other years were most likely associated with higher levels of rainfall and cooler temperatures than average during ear fill. While kernel sorters are reported to remove mycotoxin-contaminated popcorn kernels to acceptable levels, consideration of environmental factors that promote mycotoxins

in popcorn should result in more effective control measures in the field.

Keywords Aflatoxin · Fumonisin · Deoxynivalenol · Insect pests · Weather conditions · Crop rotation

Introduction

Mycotoxins are toxic and/or carcinogenic compounds produced by molds. They commonly occur in grains with high starch contents, such as wheat, barley, and maize. The three more important mycotoxins that occur in maize are aflatoxins, produced by *Aspergillus flavus*, fumonisins, produced by *Fusarium verticillioides* and *F. proliferatum*, and deoxynivalenol, produced by *F. graminearum* (Robens and Cardwell 2005). The production of these mycotoxins is influenced by different temperature and moisture conditions in the field and in storage (Payne 1999). Insect damage is another factor that can enhance levels of aflatoxins and fumonisins, and sometimes deoxynivalenol in maize (Dowd 1998; Dowd et al. 2005). The importance of insects in the mycotoxin contamination of maize has been most clearly indicated for fumonisins. Commercial hybrids of maize that produce high levels of the Bt (*Bacillus thuringiensis*) crystal protein can have greatly reduced levels of fumonisins compared to isogenic lines that do not produce the Bt protein (Dowd et al. 2005).

Popcorn is a form of maize that is highly popular as a snack food in many countries. Over 400 million kg of popcorn were produced in the U.S. in 2005 (Popcorn Board 2009). Popcorn is also subject to contamination by mycotoxins. Because popcorn is consumed by humans, tolerance levels for mycotoxins are typically lower in popcorn than for dent maize that is used for animal feed.

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For example, the U.S. was one of three countries listed with a human food maize tolerance for aflatoxin at 20 mg/kg, while the tolerance levels for aflatoxin by 51 other countries were at 5 mg/kg or less (van Egmond and Jonker 2005). For the U.S., fumonisin tolerance levels for popcorn were 3 mg/kg, while for the European Union, 0.8 mg/kg of fumonisin is the tolerance level for maize snack food (Kyprianou 2007). For Asia, aflatoxin tolerances for maize are particularly low due to high levels of hepatitis in human populations (Dohlman 2003). Levels of aflatoxin (Sekiyama et al. 2005), fumonisin (Patel et al. 1997), and DON (Abouzied et al. 1991) that may cause concern have been reported from retail samples of popcorn. However, under controlled conditions, levels of aflatoxin in popcorn have been lower than for dent maize (Saleemullah et al. 2006). Because of trade restrictions related to transgenic materials, few Bt popcorn hybrids are available or grown (D. Sleaford, personal communication). Thus, because popcorn does not have the advantage of the Bt mycotoxin control strategy, it is important to understand what conditions may influence accumulation of mycotoxins in popcorn in the field, so that economically effective control strategies can be implemented.

We now report on the incidence of mycotoxins over a 4-year period in several commercial popcorn fields grown under different conditions in central Illinois, one of the largest popcorn growing regions in the U.S. (Anonymous 2009). Temperature and rainfall conditions, as well as insect incidence, were also investigated in order to examine potential environmental influences on mycotoxin levels in popcorn.

Materials and methods

Popcorn

Popcorn was grown under irrigation using conventional agricultural practices for Central Illinois (predominately Mason Co.) from 2005 to 2008. All popcorn varieties were Weaver brand (see Table 1) and included 5 different hybrids planted at 8 different locations (although fields varied in some cases over years at the same location) (Table 1). Crops planted in the field in the prior years were also recorded when information was available due to potential influence on mycotoxin levels in the subsequent popcorn crop. Field sizes ranged between approximately 8 and 20 ha.

Sampling

Ear leaf axil debris was examined for mycotoxigenic fungi present in the field. Sampling and evaluation were

Table 1 Popcorn lines examined at different locations 2005–2008

Location	2005	2006	2007	2008
Manito 1A	W140	W140		
Manito 1B			W140	W101
Manito 1C		W140	W140	W101
Manito 2A	W133	W133		
Manito 2B			W133	W133
Forest City 1A	W119			
Forest City 2A		W163	W163	
Forest City 2B		W163	W163	W163
Forest City 2C		W119		
Forest City 2D			W119	W133
Havana 1A	W163			W163
Havana 1B		W163	W163	

All hybrids are from Weaver Popcorn Company

performed using previously described methodology for generic *Fusarium* and *F. proliferatum* (Dowd et al. 2004). In some years, *F. graminearum* and *A. flavus* primers were also used. Primers used for *F. graminearum* were described for selectivity by Wang et al. (2008), and primers for *A. flavus* were described for selectivity by Midorikawa et al. 2008.

Twenty-five milk stage ears (approximately 21 days after pollination) were individually bagged and taken from 5 locations in each field, and removed from the field for later sorting of insects and determination of damaged kernels (Dowd 2000, 2001). The same number of harvest stage ears (black-layered stage kernels) were removed in the same pattern, although in this case husks were removed in the field. Ears were again rated for types of insect damage (Dowd 2000, 2001). Insect-damaged kernels were removed and retained separately from noninsect-damaged kernels, and were hand-shelled off the ears. Incidence of visible mold on kernels was also recorded for later determinations of associations between occurrence and mycotoxin levels.

Daily rainfall data was obtained from the rain gauge nearest the sample site. Gauges are monitored by the Imperial Valley Water Authority of Central Illinois (www.outfitters.com/~ivwa/). Rain gauges are located at approximately 2.5-km intervals. The maximum distance a field was from a gauge was 2 km. Temperature data was obtained from the National Weather Service, Lincoln IL center (the nearest reliable temperature monitoring location), which is approximately 15 km from the furthest site. Past records from auxiliary weather stations at Havana and Kilbourne IL (which were no longer being maintained at the time of the present study) indicated maximum and minimum temperatures were typically within 1–2°C of the Lincoln temperatures.

Mycotoxin analysis

Kernel samples were sent to Romer Laboratory (Union, MO). Aflatoxin (B₁, B₂, G₁, G₂) was determined by HPLC with a detection limit of 1.0 µg/kg, fumonisin (B₁, B₂, B₃) was determined by HPLC with a limit of detection of 0.1 mg/kg, and deoxynivalenol (DON) was determined by HPLC with a limit of detection of 0.1 mg/kg.

Statistical analyses

Significant differences in percentage data were determined by Chi square analysis using Proc Freq (SAS Version 8.0). Significant differences in mean data were determined by analysis of variance using Proc GLM (SAS Version 8.0). Significant correlations between mycotoxin incidences and insect parameters were determined using Proc Reg (SAS Version 8.0).

Results

PCR analysis of leaf axil indicated *Fusarium* spp. were nearly ubiquitous, as indicated by detection with the generic primers. Although, *F. proliferatum* was never encountered at some sites, it was commonly encountered at other sites over the 4-year period of the study (in 2007 and 2008) (Table 2). Correlation analyses indicated no significant correlation between frequency of occurrence of *F. proliferatum* and the level of fumonisin. When examined in 2008, *F. graminearum* was more common than *F. proliferatum*. There was no significant correlation between frequency of occurrence of *F. graminearum* and total DON levels. Two-fold higher concentrations of DNA preparations did detect *F. graminearum* at a higher frequency. *F. graminearum* was detected in all 4 years at 50–100% incidence at the Manito 2 site (which was the only site assayed over the 4-year period for *F. graminearum*).

Caterpillar damage was the predominant type of insect damage present. The percent ears with caterpillar damage varied greatly between sites in each year. Typically, corn earworm (*Helicoverpa zea*) damage occurred soon after pollination, as large larvae were found on milk stage ears. European corn borer (*Ostrinia nubilalis*) damage occurred later after pollination, as small larvae were found on milk stage ears. Some western bean cutworm (*Loxagrotis albicosta*) damage occurred early after pollination in 2007 and 2008, based on the large-sized larvae found on milk stage ears. Over 50% of the popcorn ears had caterpillar damage in 2006–2008 in at least one field (Table 3).

Some *A. flavus* growth was noted on some popcorn ears in 2005, but aflatoxin was only detected in popcorn at 1.3 µg/kg for the Manito B site in 2006. Fumonisin was

Table 2 Percent incidence of mycotoxigenic fungi detected in leaf axil samples by PCR analysis

Site	<i>F. proliferatum</i>	<i>F. graminearum</i>
2005		
Manito 1	0.0	
Manito 1	0.0	
Manito 2	0.0	83.3
Havana 1	0.0	
Havana 2	0.0	
2006		
Manito 1	16.7	
Manito	0.0	
Manito 2	0.0	50.0
Forest City 1	0.0	
Forest City 2	0.0	
Forest City 3	0.0	
Havana 1	0.0	
Havana 2	0.0	
2007		
Manito 1	16.7	
Manito 1	0.0	
Manito 2	33.3	100.0
Forest City 1	16.7	
Forest City 2	0.0	
Forest City 3	0.0	
Havana 1	0.0	
Havana 2	0.0	
2008		
Manito 1	16.7	66.6
Manito 1	0.0	33.3
Manito 2	0.0	100.0
Forest City 1	16.7	16.7
Forest City 2	0.0	0.0
Forest City 3	0.0	0.0
Havana 1	0.0	66.7

F. proliferatum 1:300, *F. graminearum* 1:150 dilution of isolated DNA for PCR analysis. PCR analysis for *F. graminearum* was only performed in 2008 except for site Manito 2 where it was performed in all 4 years.

detected in popcorn at all sites in all years, with maximum levels ranging from 0.5 (2005) to 1.68 (2006) mg/kg (Table 3). A sample maximum of over 1 mg/kg of fumonisin was found for at least one site in all years, and a sample maximum above 2 mg/kg was found in 2006 and 2008. DON was also detected at some sites in all years, although maximum levels in all fields were generally much higher in 2008 than other years. Some individual samples had DON levels above 2 mg/kg in 2007 and 2008.

For samples with detectible fumonisin, levels of fumonisin in insect-damaged kernels compared to noninsect-

Table 3 Percent ears with caterpillar damage, plus mycotoxin levels, in Mason/Tazwell Cos. Sample sites in 2005–2008

Corn hybrid	% Caterpillars		Mycotoxin levels	
	Milk	Harvest	Fumonisin	DON
2005				
Manito 1A	4.0a	17.6a	0.07a	0.008b
Manito 1B	8.0a	27.2a	0.21a	0.0a
Manito 2	18.4	24.8	0.50	0.06
Forest City	0.8	-	-	-
Havana	0.0	6.4	0.44	0.0002
2006				
Manito 1A	9.6a	30.4a	1.13a	0.0004a
Manito 1B	5.6a	33.6a	0.23b	0.099a
Manito 2	3.2	20.0	0.31	0.038
Forest City 1A	4.8a	51.2a	1.28axy	0.011
Forest City 2A	4.0a	52.0a	0.47ax	0.0x
Forest City 3B	9.6	29.6	0.16	0.0x
Havana A	15.2a	58.2a	1.02axy	0.0ax
Havana B	1.6b	52.8a	1.68ay	0.014ax
2007				
Manito 1A	9.6a	23.2a	0.058a	0.0a
Manito 1B	39.2b	52.0b	0.64b	0.14b
Manito 2	11.2	10.4	0.028	0.0
Forest City 1A	7.2ax	24.8ax	0.007ax	0.32ax
Forest City 1B	8.0ax	21.6ax	0.086ax	0.0by
Forest City 2	5.6	25.6	0.0004	0.02
Havana	12.8 x	65.6 y	0.71y	0.01y
2008				
Manito 1A	18.4a	44.0a	0.10a	0.14a
Manito 1B	28.6a	54.8a	0.35a	0.025a
Manito B	7.1	26.8	0.16	0.35
Forest City 1	4.0 x	15.2 x	0.12x	1.9x
Forest City 2	1.6	12.8	0.47	0.3
Havana 1A	9.7ay	33.0ay	0.82ax	0.57ay
Havana 1B	12.9ay	22.6ay	0.17ax	0.24ay

Values in columns from the same year followed by different letters are statistically different by chi square analysis (% caterpillar infestation) or analysis of variance (mycotoxin levels); a–c values are for the same hybrid at the same location and x–z values are for the same hybrid at different locations. Fumonisin values are totals for fumonisin B₁, B₂ and B₃. Both fumonisin and DON values are in mg/kg.

damaged kernels ranged 138-fold (2008) to 559-fold (2006) higher. For samples with detectible DON, insect-damaged kernels also had much higher levels of DON than noninsect-damaged kernels, (8.8-fold in 2008 to 32.6-fold higher in 2005). Considering all samples, insect-damaged samples had higher levels of fumonisin 94–100% of the time compared to noninsect-damaged kernels. The percentage of insect-damaged kernels having higher levels of DON

than noninsect-damaged kernels varied from 100% (2005) to 27% (2008).

The highest and most frequently statistically significant (at $P < 0.05$) correlations between insect damage and fumonisins occurred for the percent ears with early caterpillar damage and fumonisin (Table 4). Although no statistically significant correlations occurred for this association in 2005, correlation coefficients were still positive, and a higher correlation was noted when only samples collected from the Manito 1 site were considered together ($R=0.50$, $P=0.07$). Additional significant associations were observed for later caterpillar damage and fumonisin in 2007, and percent ears with visibly molded kernels and fumonisin in 2006 and 2007. Again, there was considerable variability from year to year for associations between DON levels and insect damage. In 2005, there was a significant positive correlation between percent early insect-damaged ears and DON levels, and the same trend was noted at the Manito 1 site alone in 2007 ($R=0.73$, $P=0.015$). However, in 2008, there was a significant negative correlation between percent ears with late insect-damaged kernels and DON. Overall, in most cases there was no significant correlation between percent insect-damaged kernels and DON levels.

Planting of the same hybrids at multiple locations in the same year allowed for some additional statistical comparisons. In most cases, there were no significant differences between fumonisin or DON levels for the same hybrid at different locations. However, there were six instances where different fields at the same or different locations, planted with the same hybrids in the same year, had significantly different levels of fumonisin or DON (Table 3). In three of these cases, both statistically significant ANOVA and correlation analyses indicated an association between insect incidence and either fumonisin or DON levels (Forest City vs Havana in 2006 for fumonisin, Forest City vs Havana for fumonisin in 2007, Manito 1 A vs B for DON in 2007). For the other three site comparisons where there was no significant association between insect incidence and mycotoxin levels, an examination of prior crops suggested that differences in culture influenced mycotoxin levels. In 2006, the field that had popcorn the prior year (Manito 1A) had significantly higher levels of fumonisin than the one that had soybeans (Manito 1B). In 2007 and 2008, the fields that had rye planted as a cover crop after green beans (Forest City) had significantly higher levels of DON than fields that had popcorn as a prior crop (Havana). Different hybrids were not planted at comparable fields in the same year and so hybrid versus hybrid comparisons cannot be made.

Weather conditions may have influenced overall mycotoxin levels. Levels of fumonisin were significantly higher overall in 2006 (0.83 mg/kg) compared to the other years

Table 4 Correlations of insect damage and mycotoxin levels

Table 4 Correlations of insect damage and mycotoxin levels	Year	Fumonisin			Deoxynivalenol		
		Early cat	Late cat	Vis	Early cat	Late cat	Vis
Early caterpillar damage is defined as damage where pericarps are discolored. N values are 25 for 2005, 40 for 2006, and 35 for 2007 and 2008 <i>Cat</i> Caterpillar, <i>vis</i> visible mold occurrence or symptoms (“star-ring” of kernel pericarps)	2005						
	R	0.29	−0.05	−0.07	0.50	0.21	0.12
	P	0.21	0.83	0.78	0.026	0.36	0.62
	F	1.68	0.05	0.08	5.89	0.87	0.26
	2006						
	R	0.63	0.27	0.47	−0.07	0.0078	0.04
	P	<0.0001	0.084	0.0020	0.68	0.96	0.80
	F	24.69	3.15	10.9	0.17	0.00	0.06
	2007						
	R	0.86	0.50	0.76	−0.09	0.06	−0.17
	P	<0.0001	0.002	<0.0001	0.59	0.71	0.32
	F	95.73	11.22	46.48	0.30	0.14	1.03
	2008						
	R	0.35	0.08	0.24	−0.30	−0.41	−0.18
	P	0.047	0.64	0.17	0.083	0.0013	0.29
F	4.28	0.22	1.91	3.20	6.86	0.29	

Early caterpillar damage is defined as damage where pericarps are discolored. N values are 25 for 2005, 40 for 2006, and 35 for 2007 and 2008

Cat Caterpillar, vis visible mold occurrence or symptoms (“star-ring” of kernel pericarps)

(0.32 for 2005, 0.32 for 2006, and 0.24 for 2008). DON levels for 2008 (0.60 mg/kg) were significantly higher overall compared to the other years (0.065 for 2007, 0.022 for 2006, and 0.018 for 2005). Variations in weather patterns were also noted through the 2005–2008 period (Table 5). In 2006, rainfall and temperature were below normal for June, while rainfall and temperature were generally above normal for July (Table 5). For July of 2008, rainfall was above normal and temperatures were below normal, a combination that was not noted for the other years (Table 5).

Discussion

In prior studies with dent maize in the study area, *F. proliferatum* was the most commonly encountered of the *Fusarium* species that makes fumonisin, in leaf axil material (Dowd et al. 2004). There was evidence that weather conditions could influence the frequency of occurrence of these fungi in dent maize leaf axil debris (Dowd et al. 2004). *F. proliferatum* was encountered much less frequently in the popcorn leaf axils in the present study under a similar range of conditions compared to the dent maize investigated in the prior study from the same area. In 2006 and 2008 especially, July rainfall levels were very similar to those of 10.4 and 10.9 cm that occurred in 2002 and 2003 in the prior study. One possible explanation is that the more open canopy and higher axiled ears of popcorn allows sunlight to reach the leaf axils more frequently compared to dent maize, where the axils are most often shaded. This lack of shading may make the leaf axils less hospitable for *F. proliferatum*.

It is possible that stimulation of production of mycotoxins of endophytic mycotoxigenic *Fusarium* spp., which have been reported in some circumstances for some lines of dent corn (Bacon and Hinton 1996) through insect activity, is a more important source of the mycotoxin-producing fungi for popcorn than externally introduced sources. The same phenomenon may have occurred for DON as well. Factors that influence mycotoxin production which occur after the leaf axil samples were taken (such as insect damage or weather patterns) may be more important in determining absolute DON levels. Low frequency of pathogen occurrence, however, may still influence mycotoxin levels if conditions are adverse to fungal colonization.

Caterpillar damage was significantly associated with fumonisin levels in early damaged kernels in 3 of 4 years (and at one site in 2005), suggesting that insect control has the potential to significantly reduce fumonisin levels in popcorn. Bt dent corn hybrids have often shown significantly reduced levels of fumonisin in field corn compared to nonBt hybrid counterparts under natural infestations (Dowd et al. 2005). There are also indications that, in the presence of the Bt gene in maize, concentrations of DON are lower compared to hybrids that do not contain the gene (Schaafsma et al. 2002). However, few Bt popcorn hybrids are available, none are EU certified, and they are not being utilized by commercial producers due to a lack of acceptability by buyers, which appears to be related to import restrictions of different countries (D. Sleaford, personal communication). Thus, predictability models, similar to those reported for field corn (Dowd 2003; Dowd et al. 2005; De la Campa et al. 2005; Maiorano et al. 2009), may

Table 5 Weather patterns at samples sites 2005–2008

Site	Total rainfall (cm)		Mean temperature (°C)	
	June	July	June	July
2005				
Manito 1	2.44	5.54		
Manito 2	1.14	4.44		
Forest City	0.66	3.94		
Havana	3.12	4.19		
Normal	10.09	8.21	23.9 (+1.7)	24.0 (+0.1)
2006				
Manito 1	6.05	5.26		
Manito 2	5.94	12.04		
Forest City	3.45	14.61		
Havana	6.07	10.95		
Normal	10.09	8.21	21.7 (−0.5)	24.8 (+0.9)
2007				
Manito 1	11.10	7.59		
Manito 2	11.07	8.64		
Forest City	8.76	6.45		
Havana	11.58	6.81		
Normal	10.09	8.21	22.0 (−0.2)	21.9 (−1.9)
2008				
Manito 1	9.88	11.91		
Manito 2	11.63	11.84		
Forest City	11.33	9.75		
Havana	11.18	9.37		
Normal	10.09	8.21	22.9 (+0.7)	22.7 (−1.7)

Site location rainfall values are from the Imperial Valley Water Authority. Normal values from National Weather Service station in Lincoln, IL, USA

be especially valuable for use in management of mycotoxins in popcorn.

Effective insect traps or field sampling for insects, and field detection methods for mycotoxigenic fungi that can be initiated early enough (prior to silking), to provide data for predictive models that can be used to evaluate situations where treatment for mycotoxigenic fungi plus ear damaging insects may be warranted. Due to issues with mycotoxins, insect control measures may be warranted when insect damage alone (the most common reason for applications) would not be economically warranted. Even minor damage to the pericarp, such as that caused by insects, can impact popping ability (Hosney et al. 1983), which is another consideration for control that differs from conventional dent maize.

Significant reduction of DON levels in wheat treated with fungicide has been reported (Simpson et al. 2001). However, a combination of fungicide with insecticide did not result in significant increases in mycotoxin reduction

over insecticide treatments alone in maize (Folcher et al. 2009). If popcorn is planted early, treatments for insects may not be economically warranted in comparable areas. Later planted popcorn is more likely to encounter European corn borer damage, which is typically more widespread than corn earworm and western bean cutworm damage. As a result, insecticide treatments of later planted popcorn may be more warranted from a mycotoxin as well as an insect control standpoint.

The present study indicates that removal of insect-damaged kernels would result in a majority to nearly all mycotoxin removal due to the association between insect damage and mycotoxin levels, with some exceptions. It is likely that spread is occurring from insect-damaged to nondamaged kernels, and that hybrid type and/or weather conditions influence how frequently this occurs. Studies of commercial popcorn varieties have indicated no significant differences in fumonisins (Pacin et al. 2002). Although no direct hybrid to hybrid comparisons in the same field were performed in the present study, statistically significant correlation analyses with insect and mycotoxin levels that included different hybrids in the same year suggest this is also true over the period of the study. The unusual negative correlation between insect damage and DON noted in 2008 may have been due to sufficiently high DON and other fungal metabolite level such that insect growth was inhibited, as has been reported for laboratory studies where *F. graminearum* metabolites were combined (Dowd et al. 1989).

Location effects were noted for the same hybrids planted in different fields in 2007 and 2008 for both fumonisin and DON. Part of this difference for locations/fields for the same hybrid can be attributed to the differences in insect infestation, but there appear to be other causes as well. For these noninsect related instances, the fields that had popcorn planted in the prior year versus soybeans had significantly higher levels of fumonisin. Prior reports have indicated the prior crop does not influence fumonisin levels in dent maize (Munkvold 2003). Maize following maize would likely promote higher DON levels in the second maize crop, but a crop rotation control strategy has not been convincingly demonstrated (Munkvold 2003). In the present study, it appears rye as a cover crop is more likely than green beans as a prior crop to explain why DON levels were higher than when popcorn was grown the prior year for the same hybrid in different fields. Rye has been reported as a host for *F. graminearum* and is subject to seedling blight and scab (White 1999). Rye, especially when left to head and then cut as part of no-till operations, could be an inoculum source.

In conclusion, the present study indicates that both fumonisin and DON can occur at levels that will cause concern in popcorn as it comes from the field. Insect damage is the primary factor that influences the levels of

mycotoxins seen within a year, but weather conditions and the prior crop can also be important factors year to year. These factors do not always influence fumonisin and DON to the same degree.

Where available, kernel sorter cleaning can greatly reduce fumonisins in popcorn (D'Ovidio et al. 2007), but this postharvest strategy is not likely to be economically viable in all areas. Popcorn growers should avoid planting in fields that have host material for mycotoxigenic fungi. Breeding for mycotoxin resistance is another possibility, but breeding progress is particularly slow for popcorn due to the need to consider multigenic determined quality traits unique to popcorn (Ziegler 2001). Insect control can potentially be effective in preventing mycotoxin problems, under appropriate environmental conditions. Fungicide application may also be beneficial in reducing mycotoxins in popcorn, but would require studies to determine appropriate materials and timing. Predictive models would allow more effective decision making on pesticide application or early harvest and drying to limit mycotoxin problems in popcorn. Over a 4-year period, actual versus predicted values from a predictive computer program for mycotoxin levels in dent maize used for popcorn were significantly correlated, suggesting the program will require relatively minor modifications to make it suitable for popcorn (Dowd, unpublished). Reduction in mycotoxin levels in popcorn will lead to safer food for humans.

Acknowledgements We thank the Central Illinois Irrigated Growers Association and some of its growers for cooperative assistance, M. Doehring for technical assistance, and D. Sleaford, R.H. Proctor, P.J. Slininger, and F. E. Vega for comments on prior drafts of the manuscript.

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